

CYRAX™: A Portable Three-Dimensional Laser-Mapping and Imaging System

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Fig. 1 The Cyrax laser-mapping and imaging system stands about 4-ft tall and can be easily set up and operated by a single user.

Introduction

More than 60 percent of the construction done today is either renovation or expansion work as more owners focus on extending the lives of existing facilities. To plan for expansions and renovations, owners rely heavily on accurate computer aided design (CAD) models of the as-built condition of their facilities. CAD models require considerable investment to ensure that they are updated as the facility is modified. Using conventional methods to create or update models is slow, costly, and often impossible. To meet the need for a quicker, cost-effective way to create accurate three-dimensional (3-D) models, we have developed Cyrax, a portable system for acquiring 3-D data and generating 3-D models of large, complex structures.

Cyrax, shown in Fig. 1, is a completely integrated laser radar and 3-D modeling system that produces a digital model, like that of a digital camera but with added range information that provides the accurate 3-D geometry of the scanned structure. Cyrax eliminates the human error inherent in labor-intensive digitization processes like photogrammetry (in which large numbers of photographs must be taken, scanned, and tiled by hand) by automatically gathering and processing data on the entire structure. Using this stored data, accurate 3-D CAD models of any portion of the scanned structure can be produced at about one-fourth the cost. Cyrax's system provides greater range with a powerful eye-safe laser and greater time resolution. Cyrax is therefore the only technology that can collect accurate 3-D data and create 3-D digital representations and models of large objects such as oil refineries, buildings, mines, and ships.

Development of Cyrax was a joint effort between Cyra Technologies, Los Alamos National Laboratory, and the Massachusetts Institute of Technology (MIT) Lincoln Laboratory. Researchers from the Los Alamos Physics Division developed the time-interval interpolator integrated circuit, a precise time-measuring innovation that makes Cyrax possible. Cyra Technologies was responsible for developing the computer graphics perception (CGP) operating software and CAD software and integrating them with the laser and other mechanical hardware. MIT Lincoln Laboratory developed Cyrax's laser, which generates a 200-ps light pulse that is used with the time-interval interpolator to measure the two-way optical time of flight between Cyrax and an object. The success of this research and development (R&D) collaboration earned Cyrax an R&D 100 Award from *R&D Magazine* as one of the 1998's best innovations (Fig. 2).

Time Interval Interpolator Technology

The time-interval interpolator integrated circuit (Fig. 3) is a technologically significant component in Cyrax. This timing circuit marks the laser firing time and measures the return time of the laser pulse. It is the high speed of the integrated circuit that allows Cyrax to obtain accurate 3-D data at high rates. The time-interval interpolator integrated circuit used in Cyrax is the culmination of

more than eight years of research. The original aim of this research was to meet time-measurement needs of the Los Alamos nuclear weapons program, but the end result is a technology that offers time-measurement solutions for a much wider range of applications.

Before the moratorium on underground nuclear testing, researchers in the nuclear weapons program measured the time history of fast neutron growth rate as an important diagnostic tool during experiments at the Nevada Test Site. The many decades of neutron growth that occur in a very short time during a nuclear event are expressed by the following equations:

$$n(t) = n_0 e^{\int_{t_0}^t \alpha(t) dt}$$

and then,

$$\alpha(t) = \frac{n'(t)}{n(t)} = \frac{d}{dt} \log_e(n[t])$$

where n = number of neutrons, t = time, and α = neutron growth rate.

Historically, the many decades of neutron growth were measured using a series of oscilloscopes that each captured an instantaneous waveform measurement as the experiment progressed. For several decades, this labor-intensive method remained relatively unchanged from Bruno Rossi's first measurements during the Trinity experiment. In the mid-1980s, a better method was conceived that would replace the oscilloscope measurements with measurements of the times at which the growth curve crosses fixed voltages. This method automated the measurement, eliminating the labor costs of the old process.

To make such measurements possible, we developed a high-resolution time interval meter (TIM) (U.S. Patent 5,030,850) based on hybrid circuits and designed for use in high-bandwidth waveform digitizers for the precision monitoring of ultrafast electrical pulses. The waveform recorders built with these circuits proved to be very effective, achieving or exceeding the accuracy of the more labor-intensive method, but they were huge ($10 \times 6 \times 3$ ft), consumed too much power, and generated too much heat. To address these practical problems, we incorporated several technical breakthroughs that allowed us to replace the hybrid-circuit design with a low-cost, low-power, stable integrated-circuit chip without compromising performance. This Los Alamos custom chip, completed in 1994, offers a compact technology that reliably, accurately, and inexpensively makes real-time measurements at picosecond time scales. This chip opened the doors for a wide range of applications, not only for basic research, but also for innovative technologies like Cyrax that depend on that fundamental parameter of all science and technology: time.



Fig. 2 Physics Division scientists Kerry Wilson, Dan Neagley, and Clayton Smith developed the time-interval interpolator integrated circuit that gives Cyrax its accuracy and speed. Their collaboration with Cyra Technologies and MIT Lincoln Laboratory earned an R&D 100 Award in 1998.

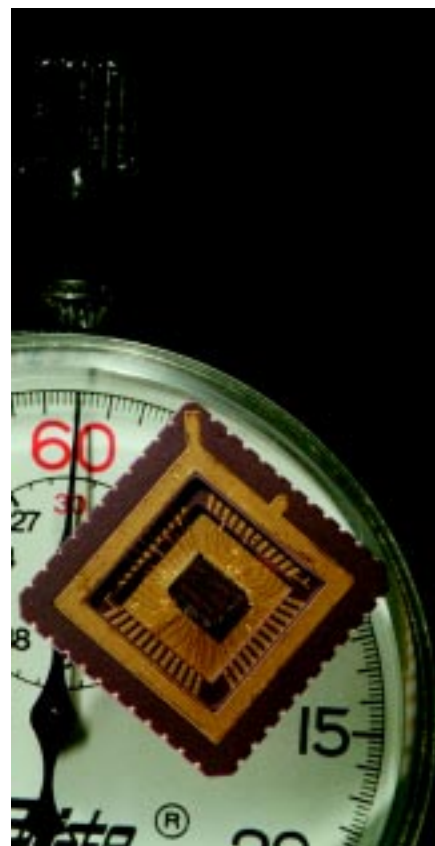


Fig. 3. The time-interval interpolator integrated circuit, shown with a stopwatch, provides precision timing for Cyrax and other applications. Much as a stopwatch dial divides each minute into 60 second interpolations of the hand's revolution speed, this integrated circuit subdivides a 100-MHz crystal clock's 10-ns cycle into 1,000 subintervals for 10-ps resolution.

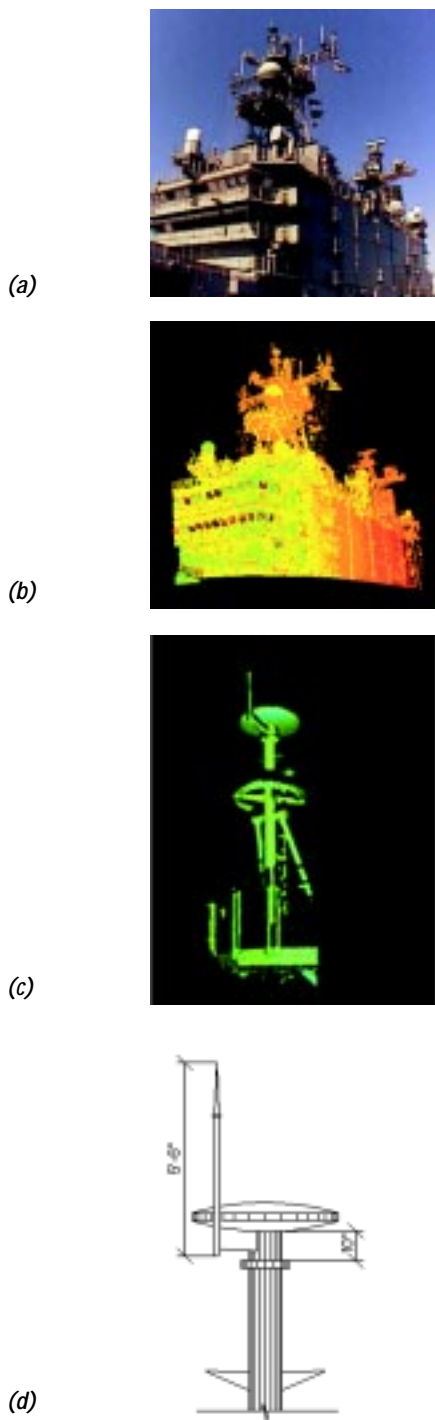


Fig. 4 In a pilot study for the U.S. Navy, Cyrax scanned the U.S.S. Tarawa's island superstructure (a). The associated software instantaneously created a 3-D digital representation (b) that was viewed on a laptop computer as scanning occurred. The data for the ship's mast were then converted into a 3-D surface model (c), which was exported to a CAD application to create an accurate, detailed 2-D drawing (d).

How Cyrax Works

Cyrax contains three primary components. The first is the field digital vision (FDV) machine, which collects the data used to image the structure. The FDV machine comprises a "laser radar" transceiver, an electromechanical scanner, an embedded computer and video camera, and associated electronics, including the time-interval interpolator integrated circuit. The second component is the CGP software application, which runs on a laptop computer to provide FDV control, dynamic visualization, modeling, and interactive 3-D editing. The third component is the software for converting 3-D data to commonly used CAD applications, such as AutoCAD and MicroStation.

Cyrax is simple enough to be operated by one person. The operator sets up the portable, tripod-mounted FDV in front of the object to be scanned. The laser has a 40° field of view and can scan objects from as far away as 100 m without loss of accuracy. The object is displayed by the video display and CGP software on a laptop computer's screen. The operator selects the region of interest and the amount of detail to be scanned by the FDV, and the FDV sends out green, passively Q-switched laser pulses (U.S. Patent 5,394,413) that scan the object as a "cloud of points." This cloud of points is a collection of mathematical points—in x , y , and z space—that represents the actual object's surface in three dimensions. The FDV determines the location of a particular point by measuring the time it takes for a light pulse to travel from the FDV laser to the surface point and back to the FDV light detector. The time interval interpolator integrated circuit measures this time interval to a precision of 10 ps and thus allows locations to be measured to a precision of 2 mm. (This time resolution and accuracy can be characterized from the TIM's own clock frequency and confirmed by the physical dimensions that are measured.) Because of the large volume of 3-D points collected, the green cloud of points appears almost solid.

As the FDV scans the scene, the CGP instantaneously displays the generated 3-D points in another on-screen window. In about an hour, the CGP converts the thousands, or even millions, of data points into representative geometric surfaces, such as the best-fitting planes and cylinders. The software adds "false" color to the representation based on the intensity of light returned by the laser, allowing details as small as 2 to 6 mm to be seen. The CGP can convert the cloud of points into a 3-D surface model that can then be exported, if necessary, to a CAD application to create two-dimensional (2-D) drawings or 3-D models (see Fig. 4).

Unlike traditional surveying and scanning equipment, Cyrax does all the data acquisition and modeling in the field in an integrated (one-step) manner. These features offer clear advantages. Data can be easily spot-checked on-site to eliminate obvious mistakes. As the model is assembled, areas requiring more detail become apparent and more data can be easily acquired. If other views of an object need to be scanned to create its 3-D representation, the operator easily moves Cyrax to another location and repeats the data

acquisition and imaging process. The CGP includes functionality that allows any number of scanning locations to be integrated into a single coordinate system; that is, the different data collections can be “zippered” together to create a single representation of the scanned object.

Applications

Cyrax’s primary application is in the architecture, engineering, and construction industry, where it is being used to create as-built CAD drawings of large structures such as buildings, ships, refineries, manufacturing operations, and transportation infrastructure. CAD drawings of these structures are extremely important for new construction and for renovation and expansion work.

In addition, Cyrax can benefit numerous other markets. For example Cyrax has already demonstrated its ability to produce accurate geologic contour maps for industries such as mining. Listed here are just a few other possible applications that show the breadth of this technology.

- *Fine Arts*. Cyrax can document artifacts for preservation and restoration projects.
- *Cinema*. Computer models generated by Cyrax can be used to create realistic special effects. For example, caves measured by Cyrax were used to create background models in the film *Starship Troopers*.
- *Law Enforcement*. Cyrax can generate detailed, accurate archival images of accident and crime scenes.
- *Parts Listing*. Cyrax can recognize shapes in the scanned data and create parts lists for structures as complicated as oil refineries.
- *Facility Management*. Cyrax can provide accurate, detailed structural data throughout a facility’s lifetime, allowing facility managers to easily assess the need for and feasibility of redesign as safety standards and facility needs change.

Cyrax has been tested by the U.S. Navy, Fluor Daniel, Raytheon, and Chevron. The results of this testing have produced accurate, detailed images that far exceed other available techniques. Although still a fledgling technology, Cyrax is already changing the way industry looks at 3-D imaging. We anticipate that Cyrax will have profound impacts in many applications, and it will affect our lives over the next few years in ways we can only begin to imagine.